HTR Process Heat Applications: Present and Future

High-Temperature Reactors for Liquid-Fuels Production

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Process Heat Applications Special Session
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4th International Topical Meeting on High-Temperature Reactor Technology
September 28-October 1, 2008
Washington D.C.

Energy Futures May Be Determined By Two Sustainability Goals

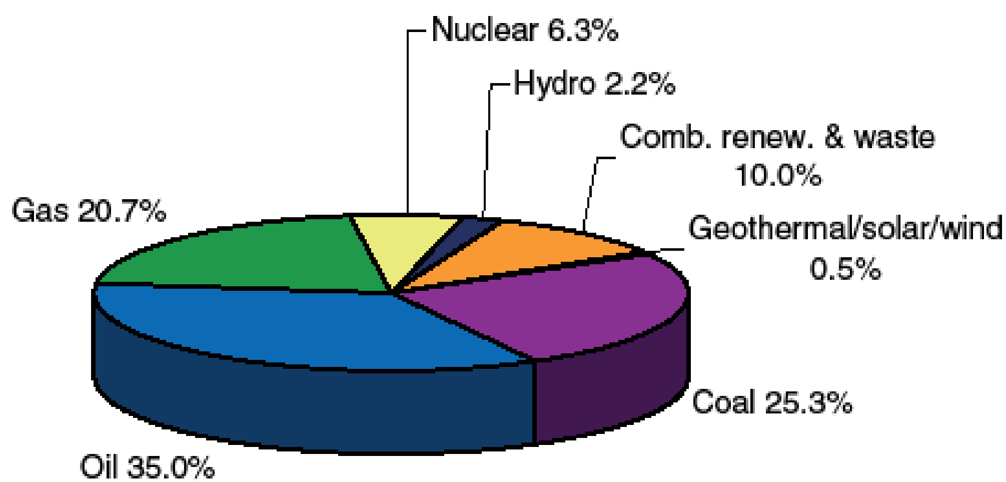
No Imported Crude Oil **No Climate Change**

Athabasca Glacier, Jasper National Park, Alberta, Canada
Photo provided by the National Snow and Ice Data Center

Oil is the Energy Challenge

Share of Total Primary Energy Supply* in 2005

World



Oil: Largest Source of Energy
World Cost: $ 3-4 Trillion/year

11 434 Mtoe

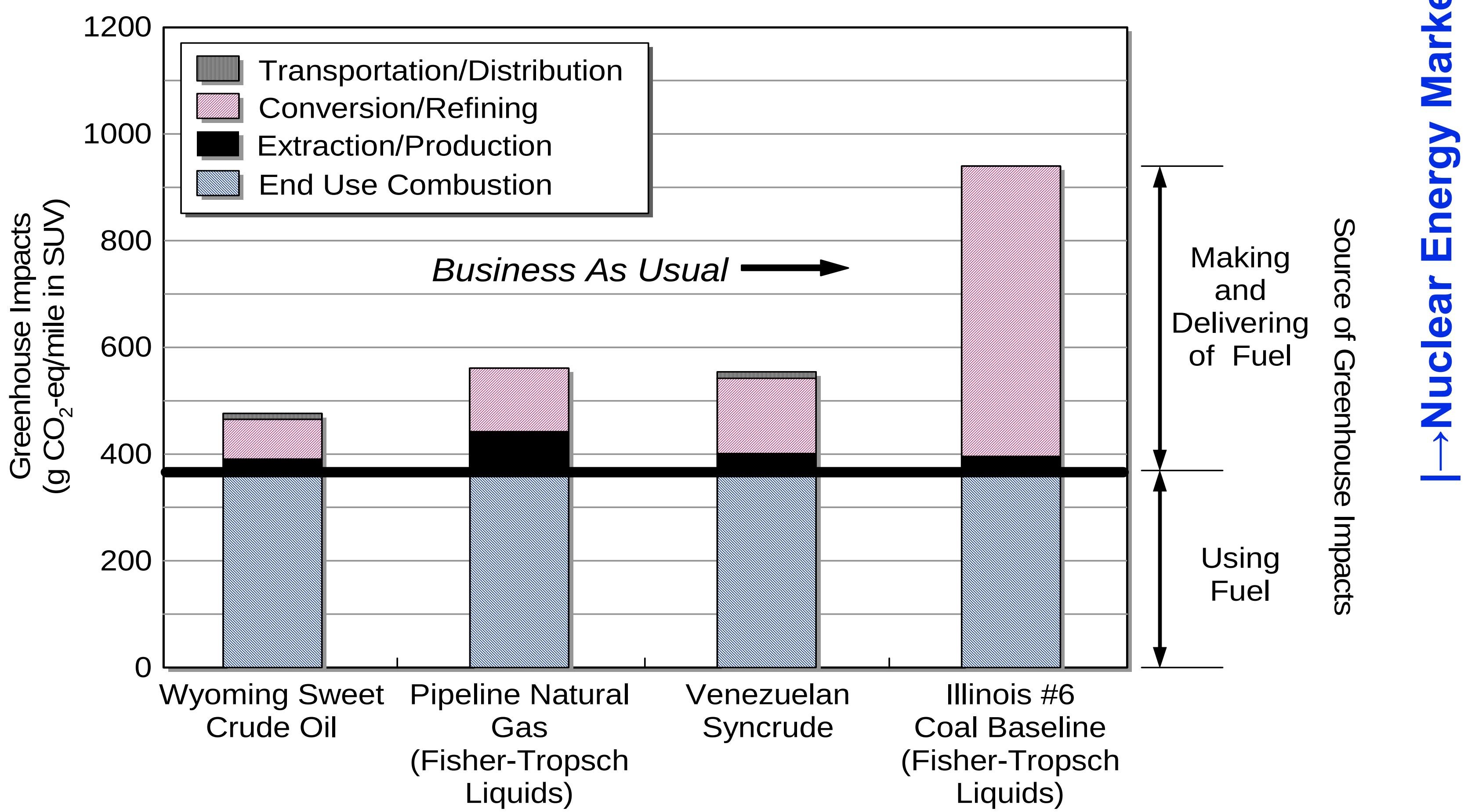
* Share of TPES excludes electricity trade.
Note: For presentational purposes, shares of under 0.1% are not included and consequently the total may not add up to 100%.

Use of High-Temperature Reactors (HTRs) for Liquid Fuels Production

- Conversion of crude oil, shale oil, coal, and biomass to liquid fuels is energy intensive
- HTRs can provide the high-temperature heat
  - Centralized steady-state heat source required
  - Replace burning of fossil fuels or biomass
  - Reduce greenhouse gas releases

Conversion of Fossil Fuels to Liquid Fuels Requires Energy

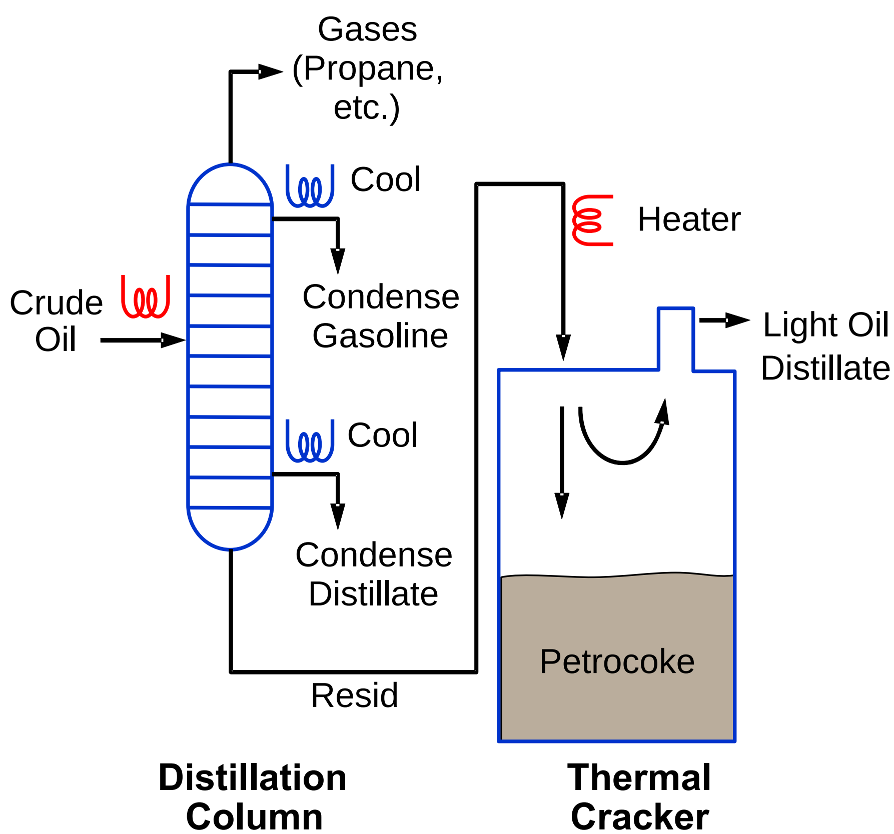
SUV (Car) greenhouse Impacts from per mile (Below horizontal bar) and from the fuel production cycle (Above horizontal bar)



Traditional Refineries

Existing High-Temperature Heat Market

Refineries Consume ~7% of the Total U.S. Energy Demand



Traditional Refining

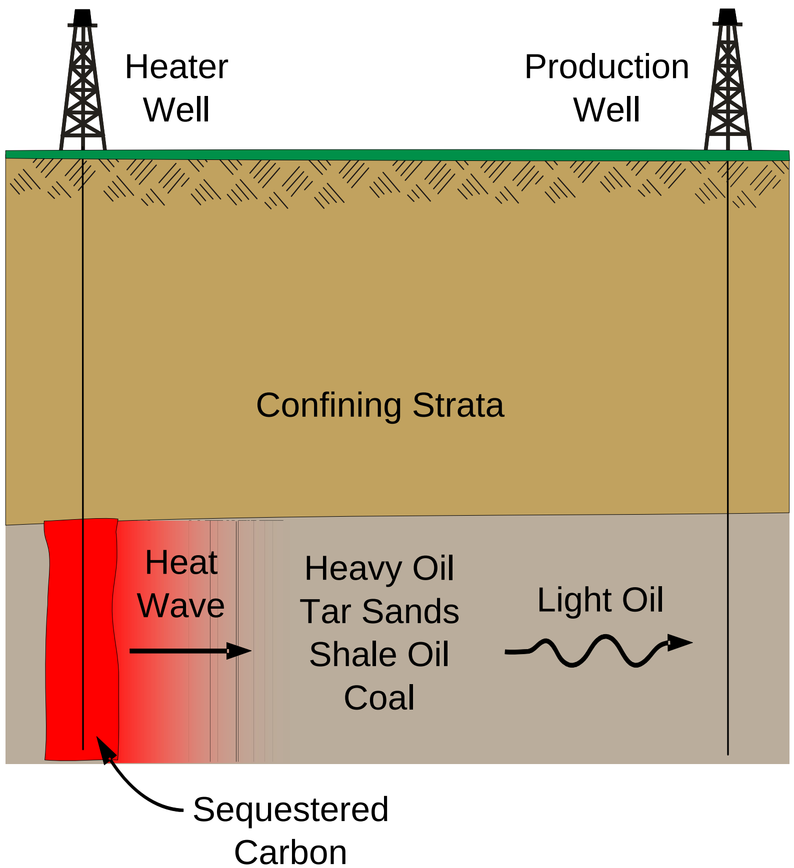
- Energy inputs
  - Heat to 550°C
  - Some hydrogen
- HTRs could replace natural gas and crude oil
- Market size equals existing nuclear enterprise

Underground Refining

New Technology to Increase U.S. Oil Production

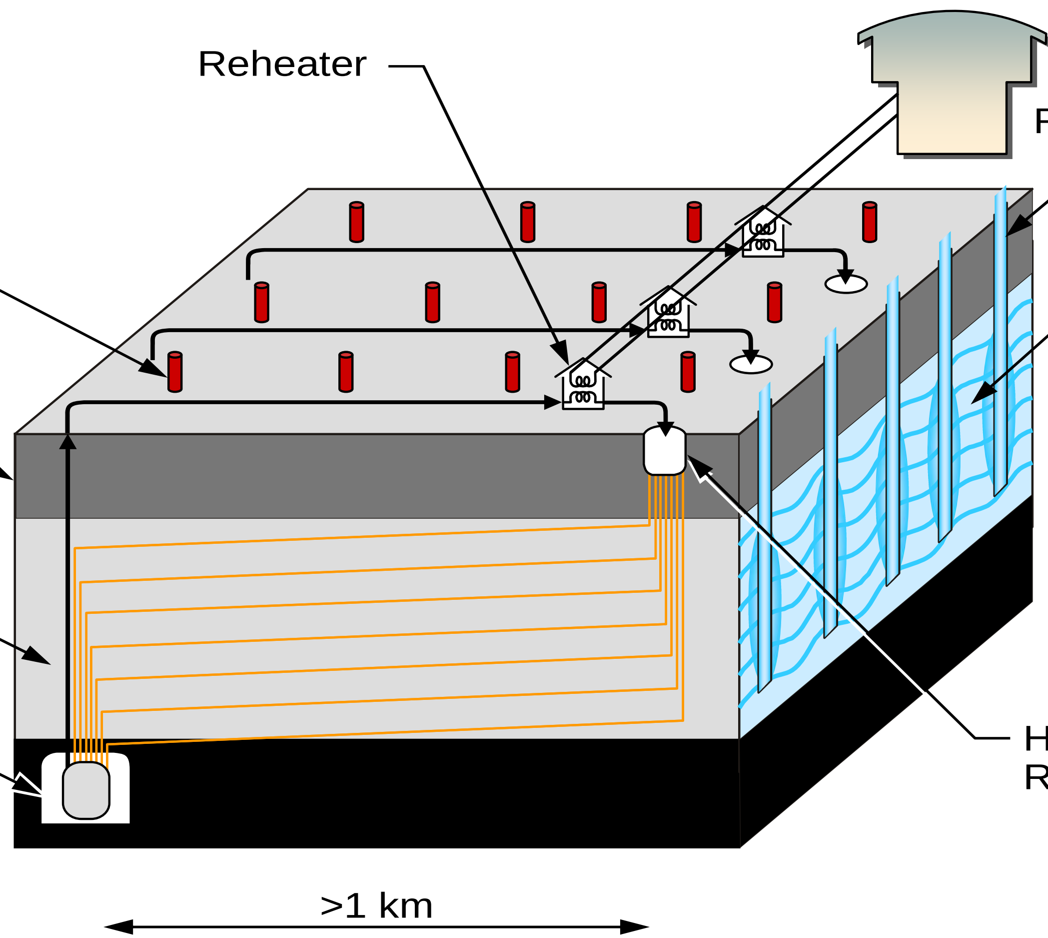
Underground Refining (Production) Could Make the U.S. Oil Sufficient

- Method to obtain oil from U.S. resources
  - Oil shale
  - Depleted oil fields
  - Heavy oil deposits
- Heat fossil deposits
  - Thermally crack organics into light oil and carbon residue
  - Recover light crude oil
  - Carbon residue sequestered underground as carbon



In-Situ Refining

Underground Refining Requires Massive Quantities of High-Temperature Heat



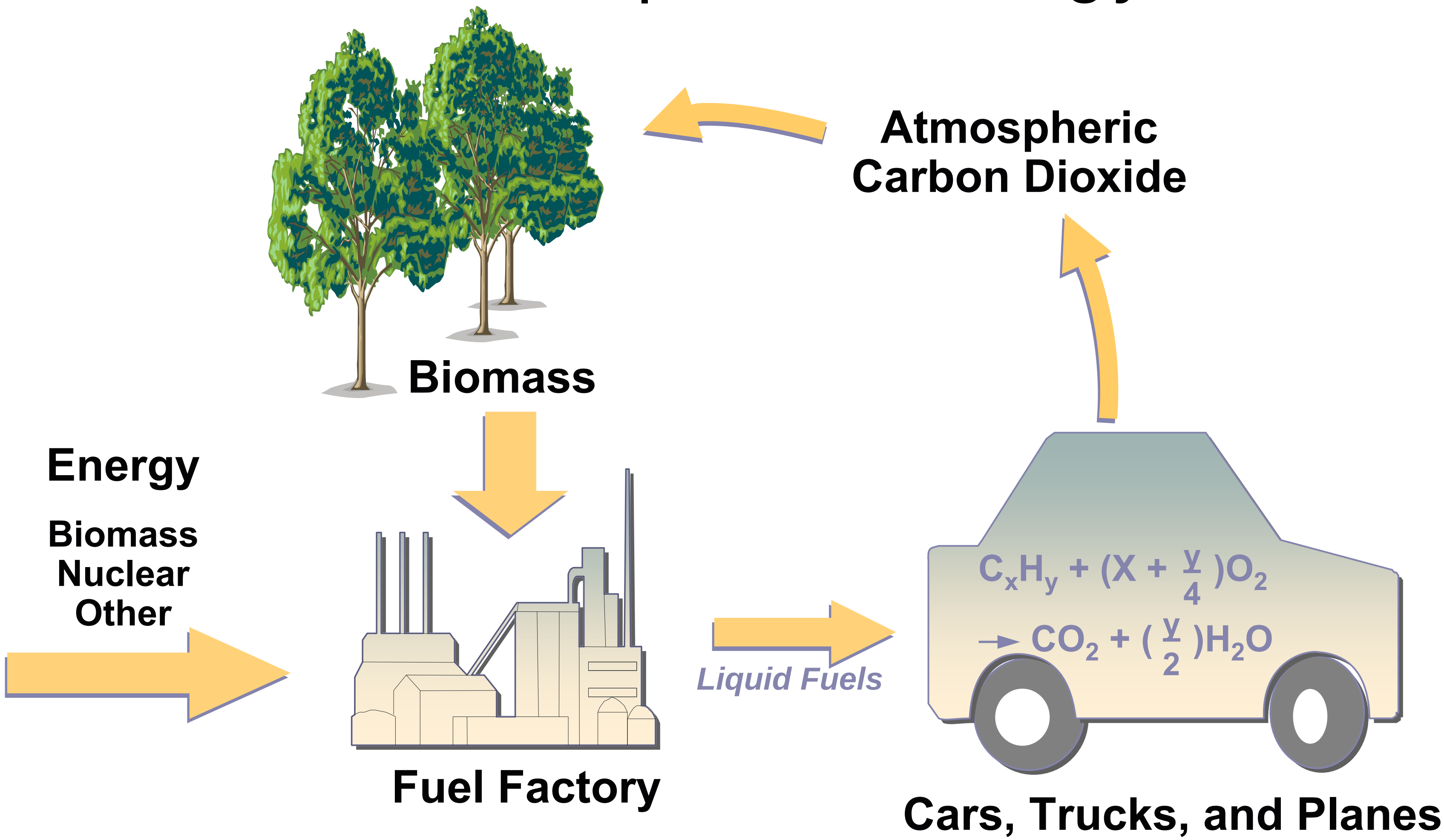
High-Temperature Reactor Provides 600-700°C Heat
Avoids Burning a Third of the Fossil-Fuel Product to Recover the Oil

Biomass to Liquid Fuels

Boost Liquid Fuels per Ton of Biomass

Existing and Future Application

Conversion of Biomass to Liquid Fuels Requires Energy



Biomass: Worldwide Resources Measured in Billions of Tons per Year

Without Significantly Impacting Food, Fiber, and Timber

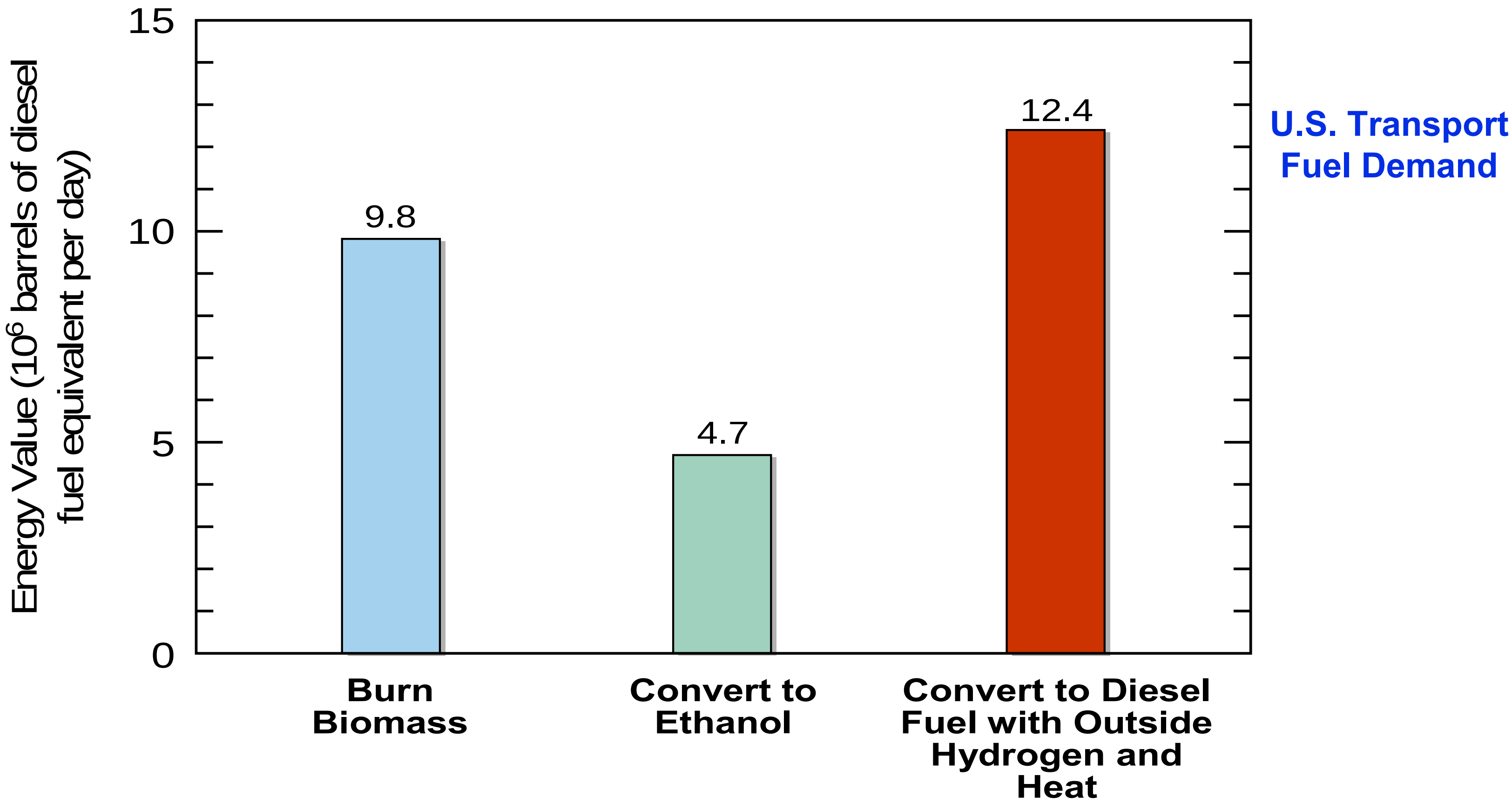
Agricultural Residues

Logging Residues

Urban Residues

Algae and Kelp (Ocean)

External Heat and Hydrogen Increases Liquid Fuel Per Unit of Biomass



Energy Value of 1.3 Billion Tons/year of U.S. Renewable Biomass Measured in Equivalent Barrels of Diesel Fuel per Day

Nuclear Heat Maximizes Liquid Fuels Production Per Ton of Biomass

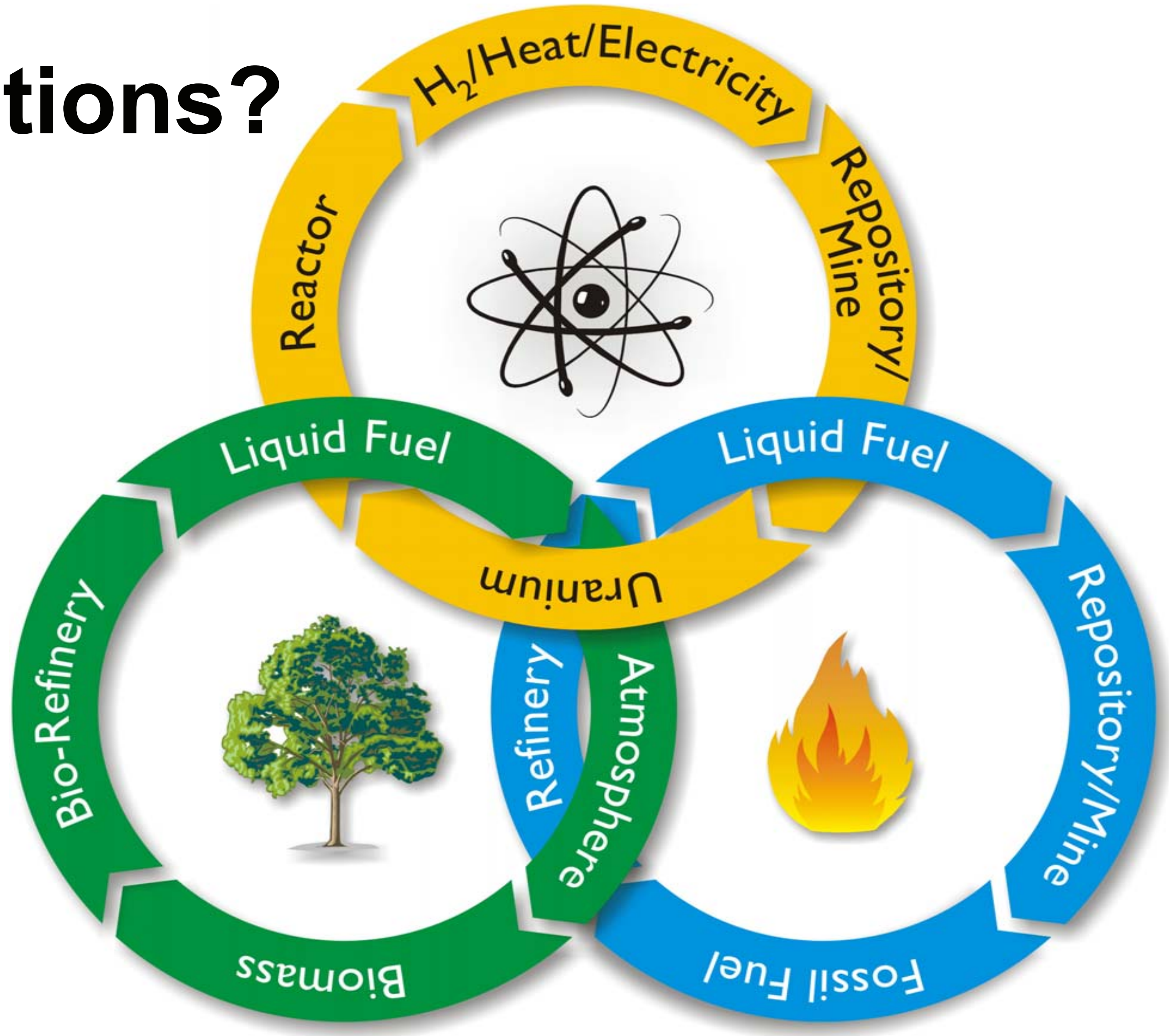
- **Biomass is the limiting resource**
- Nuclear heat replaces biomass for process heat in the liquid-fuels production plant
- Maximize liquid fuels per ton of biomass

Algae

Conclusions

- Energy for transport is the grand challenge.
  - World security risk
  - High costs (~$3 trillion/year)
  - Greenhouse impacts
- Conversion of any feed stock (crude oil, oil shale, biomass, etc.) to a liquid fuel (gasoline, diesel, ethanol) is energy intensive
- Most liquid fuels processes require high-temperature heat; thus incentives for HTRs

Questions?



H_2/Heat/Electricity
Repository/Mine
Reactor
Uranium
Liquid Fuel
Bio-Refinery
Biomass
Atmosphere
Liquid Fuel
Refinery
Repository/Mine
Fossil Fuel

Biography and References

Dr. Charles Forsberg is the Executive Director of the Massachusetts Institute of Technology Nuclear Fuel Cycle Study. Before joining MIT, he was a Corporate Fellow at Oak Ridge National Laboratory. He is a Fellow of the American Nuclear Society, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 10 patents and has published over 200 papers.

1. C. W. Forsberg, "Sustainability by Combining Nuclear, Fossil, and Renewable Energy Sources," *Progress in Nuclear Energy*.
2. C. W. Forsberg, "Nuclear Energy for a Low-Carbon-Dioxide-Emission Transportation System with Liquid Fuels," *Nuclear Technology*, **164**, December 2008.
3. C. W. Forsberg, "Meeting U.S. Liquid Transport Fuel Needs with a Nuclear Hydrogen Biomass System," *International Journal of Hydrogen Energy* (2008), doi.10.1016/j.ijhyden.2008.07.110
4. C. W. Forsberg, "Use of High-Temperature Heat in Refineries, Underground Refining, and Bio-Refineries for Liquid-Fuels Production," HTR2008-58226, *4th International Topical Meeting on High-Temperature Reactor Technology, American Society of Mechanical Engineers; September 28-October 1, 2008;Washington D.C.*
5. C. W. Forsberg, "An Air-Brayton Nuclear Hydrogen Combined-Cycle Peak- and Base-Load Electric Plant," CD-ROM, IMECE2007-43907, *2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, Washington, November 11-15, 2007*, American Society of Mechanical Engineers, 2007
6. C. W. Forsberg, "Economics of Meeting Peak Electricity Demand Using Nuclear Hydrogen and Oxygen," *Proc. International Topical Meeting on the Safety and Technology of Nuclear Hydrogen Production, Control, and Management, Boston, Massachusetts, June 24-28, 2007*, American Nuclear Society, La Grange Park, Illinois.

High-Temperature Reactors for Liquid Fuels Production

Charles Forsberg

Historically, nuclear power has been used to generate electricity. That may change. The worldwide cost of oil is three to four trillion dollars per year—in addition to the risks associated with dependence on foreign oil and concerns about climate change. In addition to crude oil, liquid transport fuels can be produced from many other feedstocks such as biomass, heavy oil, shale oil, and coal. However, the processes for converting these feedstocks into liquid fuels require massive quantities of energy. Low-carbon nuclear power can provide that energy and thus maximize the liquid fuels production per unit of biomass or fossil fuel while minimizing greenhouse gas releases. In most cases, high-temperature heat is required; thus, the incentives for development of high-temperature reactors (HTRs).

Simultaneously, the use of HTRs may enable underground refining where heat is used insitu to convert heavy oil, oil sands, shale oil, and soft coal into a high-grade light crude oil and a carbon residue. This would dramatically increase worldwide resources of "recoverable" oil. The process is similar to the thermal cracking of heavy oils in refineries. However, in refineries the carbon residue is petrocoke that is burnt as fuel. Underground refining results in in-situ carbon sequestration of this residue in the form of carbon and significantly lower greenhouse impacts from liquid-fuels production.

The potential for nuclear-biomass fuels is equally large. This potential can be shown by example. The U.S. could produce ~1.3 billion tons of renewable biomass per year. The energy value of that biomass is equivalent to burning ~10 million barrels of diesel fuel per day. If that biomass is converted into ethanol and biomass is used to provide the energy for the conversion process, the energy value of the fuel ethanol is equal to ~5 million barrels of oil per day. However, if low-carbon nuclear energy is used to provide energy to biomass conversion plants, all the biomass can be converted into hydrocarbon liquid fuels and the equivalent of ~12 million barrels of diesel fuel could be produced per day.

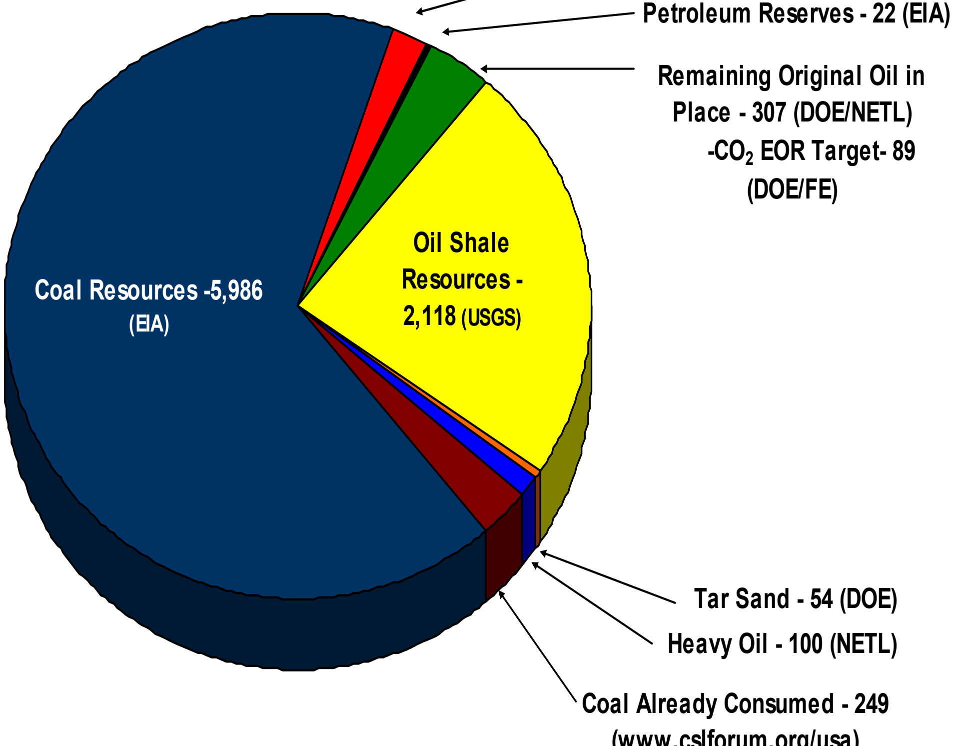
The ultimate potential for biofuels may be much larger. Corn yields have increased by a factor of 10 over 80 years and the same may occur for fuel crops such as sawgrass on lands unsuitable for crops. Simultaneously, biomass forms such as algae have the potential for biomass yields an order of magnitude greater per unit area of land than traditional sources of biomass. However, all biomass forms have high water contents and thus require significant heat for processing—something that nuclear energy can provide.

The U.S. Has the Largest Fossil Resources Potentially Suitable for Underground Refining

Could Exceed All *Petroleum Already Consumed*

- Primary candidates for in-situ refining
  - Shale oil (Very large resource)
  - Depleted oil fields (Remaining oil in place)
  - Heavy oil
- Secondary candidates for in-situ refining
  - Tar sands (small U.S. resource)
  - Coal (Limited information, only some coals are candidates)
- In all cases in-situ viability is dependent upon local geology—only some sites suitable

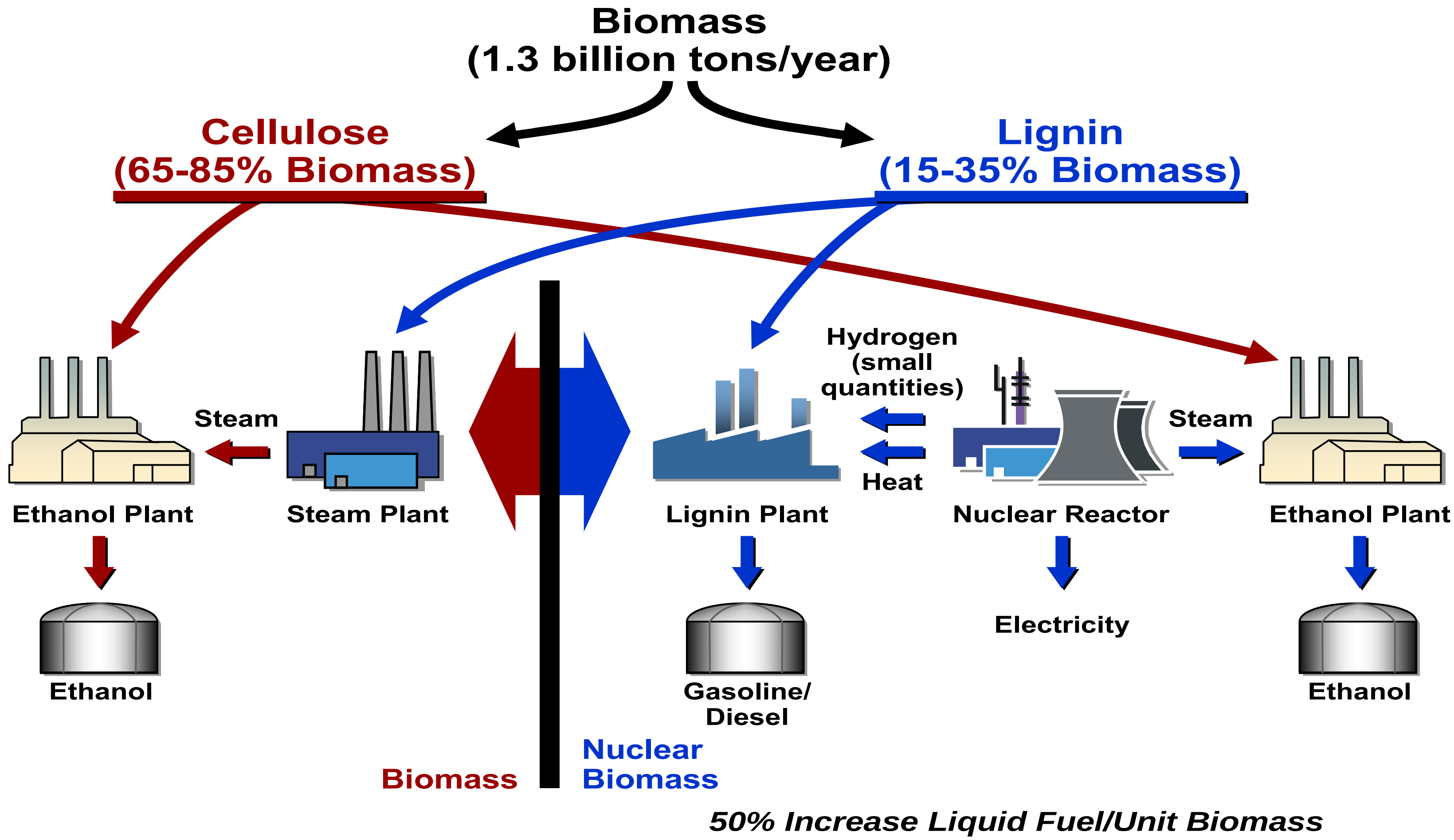
U.S. Solid and Liquid Fuels Resources
(Total endowment 9,033 billion bbls oil equivalent*)



Units are in billion bbl-oil-equivalent coal - 10K BTU/lb; oil - 6M BTU/bbl

*not including energy losses in transformation to liquid fuel

Cellulosic Liquid-Fuel Yields Increase Per Unit Biomass If Use Nuclear Heat and H_2



Nuclear Option Requires Development of Lignin to Liquid Fuel Conversion Process to Beneficially Use All the Lignin

4th International Topical Meeting on High Temperature Reactor (HTR) Technology

Process Heat Applications Special Session

October 1, 2008 • 1:00 pm – 4:00 pm

Renaissance Hotel; 999 Ninth Street, NW • Washington, DC

1:00 pm – 1:15 pm	**Welcome Statement** **Mr. Dennis Spurgeon**, *U.S. Department of Energy, Assistant Secretary of Energy* **Purpose of Today's Special Session** **Mr. Richard Black,** *U.S. Department of Energy, Associate Deputy Assistant Secretary of Nuclear Energy*
1:15 pm – 2:15 pm	**Panel 1: Executive Overview: Process Energy — U.S. Market Demands** ***Facilitator***: **Dr. Bill Rogers**, Idaho National Laboratory
	Petrochemical Industry: Dow Chemical **Mr. Fred Moore**, *Global Director of Manufacturing & Technology* Tertiary Oil Recovery & Extractions from Tar Sands & Shale: Chevron **Mr. Jeffry Hedges**, *Division Manager of Integrated Laboratory Technologies* Owners & Operators, Nuclear Power Plants: Entergy Corporation **Mr. Dan Keuter**, *Vice President, Planning and Innovation* Owners & Operators, Coal-to-Liquid (CTL) Plants: Shaw Stone & Webster Management Consultants **Mr. Reiner Kuhr**, *Senior Executive Consultant*
2:15 pm – 2:30 pm	**Panel 1: Facilitated Question and Answers**
2:30 pm – 3:00 pm	**Panel 2: Nuclear Technology & Resource Options** ***Facilitator***: **Mr. Phil Hildebrandt**, *Idaho National Laboratory*
	Westinghouse Electric Company **Dr. Regis Matzie**, *Senior Vice President & Chief Technology Officer* Idaho National Laboratory **Mr. Michael Hagood**, *Energy Systems Business Lead* *Idaho National Laboratory* Areva NP Inc. **Dr. Finis Southworth**, *Chief Technology Officer* General Atomics **Dr. Arkal Shenoy**, *Director, Modular Helium Reactors Program*
3:00 pm – 3:15 pm	**Panel 2: Facilitated Question and Answers**
3:15 pm – 3:45 pm	**Panel 3: Process Heat Applications: Near- & Long-Term Solutions** **Facilitator**: **Mr. Tom O'Connor**, *Department of Energy*
	HTR Process Heat Applications, Present & Future **Dr. Charles Forsberg**, *Massachusetts Institute of Technology, Department of Nuclear Science and Engineering.* Idaho National Laboratory, Nuclear Hybrid Energy Systems **Dr. Richard Boardman**, *Energy Security Initiative Lead , Idaho National Laboratory*
3:45 pm – 4:00 pm	**Panel 3: Facilitated Question and Answers**
4:00 pm	**Closing Remarks**